AN INVESTLARKS AND HEARTS: CIRCADIAN MISMATCH AND EFFORT INTENSITY

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My experiment concerned the influence of chronobiological (circadian) rhythm on fatigue, effort, and cardiovascular (CV) response. It evaluated responses of morning people (larks) presented an easy or difficult recognition memory task at a time congruent or incongruent with their rhythm. Based on an extension of a conceptual analysis of fatigue influence, my central prediction was that circadian rhythm would combine interactionally with task difficulty to determine effort and associated CV responses. Specifically, effort and associated CV responses were expected to be (1) positively correspondent to task difficulty in the morning (stronger where difficulty is high), but (2) negatively correspondent to difficulty in the evening (stronger where difficulty is low). Preliminary results showed concerning gender effects on difficulty appraisal of the task, thus we examined women and men's data separately. CV findings for women were broadly, but not completely, consistent with predictions. Analyses revealed no group differences in CV response for lark men.

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CHAPTER 1

INTRODUCTION

Recent research has looked at the effects of fatigue (performance resource depletion) on effort and associated cardiovascular (CV) responses (Wright, 2014; Wright & Stewart, 2012). The guiding analysis of fatigue influence includes three core components that can be described as follows.

A. First, the analysis draws from Obrist (1976) the hypothesis that certain CV responses – specifically, those associated with beta-adrenergic stimulation - vary with effort. The higher the level of effort, the more pronounced should be its associated CV responses.

B. Second, the analysis uses Brehm's motivation intensity theory (MIT; Brehm & Self, 1989) to predict when people will exert different amounts of effort. Theoretically, effort should be determined directly by the difficulty of the performance challenge (task) at hand. Effort should increase with difficulty as long as success is viewed as possible and worthwhile. If success is viewed as impossible or too difficult considering its importance, effort should be low. In theory, the role of success importance should not be to determine effort directly. Rather, the role should be to determine effort indirectly by setting the upper limit of what performers will be willing to do in a performance situation.

C. Third, the analysis assumes: (1) that appraisals of performance challenge difficulty rise as ability in the relevant performance domain falls, and (2) that ability falls as fatigue rises. People who are less capable in an area (e.g. computer programming) should perceive any given challenge within that area (e.g. coding operations for a statistical procedure) as harder than should people who are more capable in the area. Further, people who are fatigued should be less capable than people who are rested. As a result, they should see challenges as more daunting.

Implications and Evidence

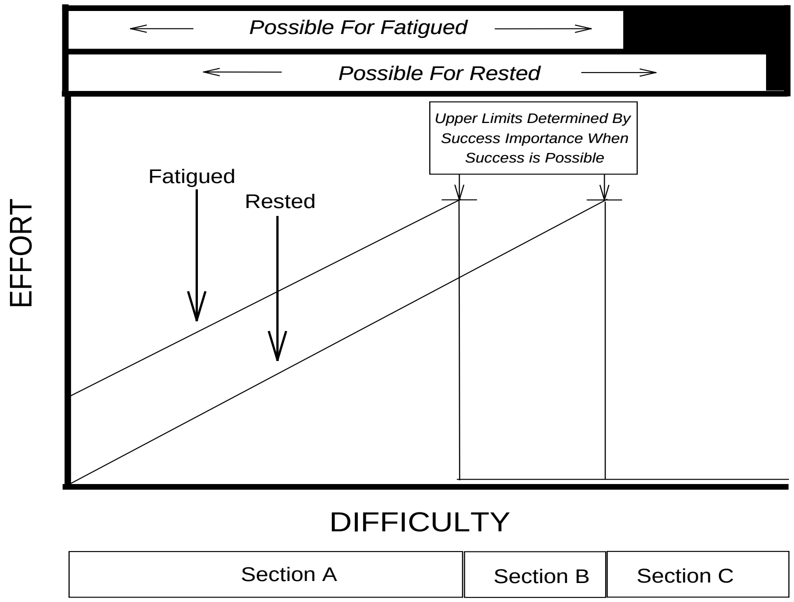

Figure 1. Effort deployment model (Wright and Kirby, 2004).

Figure 1 displays a model of effort deployment that follows from the analysis. The model involves both fatigued and rested performers and highlights three key implications. One implication is that fatigued individuals should exert more effort and have stronger CV responses than rested individuals as long as they see task success as both possible and worthwhile (Section A). A second is that fatigued individuals should withhold effort at lower objective difficulty levels than rested individuals. Fatigued individuals should do so because they should conclude more quickly (at lower difficulty levels) that success is either excessively difficult (given success importance) or impossible. So long as rested individuals view success as possible and worthwhile and fatigued individuals do not, effort and associated CV responses should be greater for the rested group (Section B). The third implication is that if a task is (objectively) difficult enough, even rested individuals should withhold effort. This means that fatigue should be unrelated to effort and associated CV responses if requirements to meet a performance challenge exceed the upper limit of what both rested- and fatigued performers can or will do. Specifically, effort and associated CV responses should be low for both performance groups (Section C).

The preceding implications have received consistent empirical support in CV response studies that have evaluated fatigue influence under different challenge difficulty conditions (e.g. Schmidt, Richter, Gendolla, & Van der Linden, 2010; Stewart, Wright, Hui, & Simmons, 2009; Wright, Patrick, Thomas & Barreto, 2013). Consider for example an experiment (Wright, Martin, & Bland, 2003) that (1) first required participants to perform an easy (fatigue low) or difficult (fatigue high) counting task, and then (2) presented participants math problems with instructions that they could earn a prize by attaining a low- (easy) or high (difficult) performance standard. As predicted, analysis of CV responses assessed during work indicated a fatigue x difficulty interaction for systolic blood pressure (SBP) response, with similar response patterns emerging for diastolic blood pressure (DBP) and mean arterial pressure [MAP – the average pressure across a heart (beat-to-beat) cycle]. Whereas responses tended to be greater for high fatigue participants when difficulty was low, they were the reverse of this when difficulty was high. The pattern was expected for SBP, as SBP responses are influenced by heart contractility, which is considered to be an especially sensitive beta-adrenergic activation index (Brownley, Hurwitz, & Schneiderman, 2000).

Consider also an experiment that used a very different task and method of fatigue induction (Wright, Shim, Hogan, Duncan, & Thomas, 2012, Experiment 1). It first required participants to walk on a treadmill for 10 minutes while wearing a vest weighted at either 5- (low fatigue) or 25 (high fatigue) pounds. After the 10 minutes of walking, participants pedaled a stationary bicycle for an additional 10 minutes with instructions that they would receive a prize if they maintained an easy cycling speed (40 rpm) or a difficult cycling speed (60 rpm). Once again, analysis of SBP responses assessed during work indicated an interactional pattern, in this case with heart rate (HR) responses following in close order. Whereas responses were greater for high fatigue participants when difficulty was low, they were greater for low fatigue participants when difficulty was high.

Extension to Circadian Mismatch

The present research was designed to extend the fatigue analysis discussed above to the phenomenon of *circadian mismatch*. Circadian mismatch as a concept pertains to the notion that the human body has different chronobiological (circadian) rhythms. These rhythms are roughly 24-hour cycles and modulated by both temperature and sunlight. The most commonly known chronobiological rhythm is the sleep-wake cycle. *Chronotype* is the classification of people as early- and late risers. These riser groups have come to be known in the research literature as larks and owls, respectively. Larks are more likely to rise early with a surge of energy. They feel fatigued at night and sleep earlier. Owls are more likely to rise late. They feel fatigued upon waking and sleep later. Circadian match exists when larks and owls perform at preferred times of day - larks in the morning and owls at night. Circadian mismatch exists when larks and owls perform at non-preferred times of day - larks at night and owls in the morning.

Given the propensity of larks and owls to feel fatigued at different times of the day, it follows from the fatigue analysis that they should display distinctive CV response profiles corresponding to those depicted for fatigued and rested performers in Figure 1. Specifically, the analysis suggests:

1. Mismatched performers should evince stronger effort and associated CV responses so long as they view success as possible and worthwhile.

2. Mismatched performers should withhold effort at a lower difficulty level than should matched performers. So long as matched individuals see success as possible and worthwhile and mismatched individuals do not, effort and associated CV responses should be greater for the matched group.

3. If a task is (objectively) difficult enough, even matched performers should withhold effort. When this holds true, chronobiological rhythm should bear no relation to effort and associated CV responses. Both matched and mismatched performers should withhold effort and display little CV arousal.

Evidence for the Application

Whereas empirical indications pertaining to the guiding fatigue analysis are straightforward, those pertaining to the analysis' extension to circadian mismatch are uncertain, at best. Investigators have conducted relevant CV response studies; however, findings from the studies have been mixed in character and not easily interpreted. The earliest CV response study, by Nebel, Howell, Krantz, Falconer, Gottdeiner and Gabbay (1996), presented small groups of male participants (*n*'s = 19 and 11) mental (e.g., Stroop, mental math) and physical (hand grip) challenges in the early morning and at noon. Results indicated chronotype x time interactions for HR and rate-pressure product (RPP = SBP x HR) responsiveness during performance of the mental tasks, with larks evincing stronger CV responses than owls in the earlier period and owls evincing stronger responses than larks in the later period. Follow-up research by Willis, O'Conner and Smith (2005) attempted to replicate using a larger sample that was mixed in terms of gender (32 men, 28 women). It presented a series of psychological challenges – mental math, mirror tracing, social speaking - in the early morning and early afternoon. Analysis of HR and blood pressure responses adjusted for baseline indicated no effects involving chronotype, that is, lark-owl status.

The most recent CV response research, by Roeser, Obergfell, Meule, Vögele, Schlarb and Kübler (2012), involved a sample of 55 women – roughly half larks and roughly half owls. Participants were presented a mental math challenge in early- to mid-morning (8-11am) or in late afternoon- to early evening (4-7pm). Results indicated only chronotype main effects, reflecting stronger SBP and HR responses and reduced heart rate variability among the owls.

In view of the preceding findings, it might be tempting to conclude that extension of the fatigue analysis to circadian mismatch has no merit. However, it is of note that none of the existing studies examined interactions involving chronotype, difficulty, and time of day. Indeed, difficulty was not considered as a variable of possible interest. Further, the studies involved disparate participant samples and critically different session protocols. Whereas the earlier projects involved within-participant designs, the most recent study involved a between-participant design. Whereas the earlier projects separated early morning responses from noon and early afternoon responses, the more recent study separated early- to mid-morning responses from late afternoon- to early evening responses. Other variations of note involved sample size, task characteristics (e.g., math versus social speaking), and conditions under which participants performed. Considering the number of study differences as well as the small number of studies that have been conducted, a wiser conclusion would be that additional research is needed – with the additional research being guided by a well-considered conceptual analysis such as the present fatigue formulation.

Present Research

The present study was designed to test the fatigue analysis extension directly, initiating a program of research that will examine systematically the full set of extension implications. It evaluated specifically the hypothesis that chronotype (lark-owl) influence on effort and associated CV responses should be determined jointly by the time at which a performance challenge is confronted and the difficulty of the performance challenge. For purpose of efficiency, it included only larks and manipulated two factors: (1) the time of day tested, and (2) task difficulty. In addition to examining traditional measures of blood pressure (SBP, DBP, MAP) and HR, it measured heart contraction force – considered the most sensitive noninvasive index of beta-adrenergic activation. The study measured contraction force (heart contractility) conventionally in terms of heart pre-ejection period (PEP). PEP is the time in milliseconds between initiation of left ventricular contraction and expulsion of blood into systemic circulation.

Participants identified in advance as larks were assigned trials of an easy or moderately difficult recognition memory task with the opportunity to win a modest prize if they were 85% successful. Half were assigned a morning session (8-11am) and half were assigned an evening session (5-8pm). The main prediction was that effort and associated CV responses would be (1) positively correspondent to difficulty in the morning (stronger when difficulty was high), but (2) negatively correspondent to difficulty in the evening (stronger when difficulty was low; Table 1). Larks were expected to view the more difficult task as possible and worthwhile in the morning, but as excessively difficult in the evening. Further, larks were expected to view the less difficult task as especially easy in the morning. Given the special sensitivity of PEP to beta-adrenergic activation and the influence of heart contractility on SBP, I expected PEP and SBP to be especially likely to reflect the interactional pattern expected for effort.

Table 1

Predicted Effort and Associated CV Response

	Morning	Evening
Easy	*lower*	*higher*
Difficult	*higher*	*lower*

Although my main prediction was for the experimental factors to interact in a crossover fashion to determine effort and associated CV responses, it is important to note that I recognized that other response patterns could emerge and still be consistent with the guiding fatigue analysis. For example, there was the chance that the lark participants would perceive the more difficult task as possible and worthwhile in the evening as well as in the morning. If they did, one would expect two main effects for effort and associated CV responses. Specifically, effort and associated CV responses should be stronger overall under difficult task conditions and stronger overall in the evening. There also was the chance that the lark participants would perceive neither task as possible and worthwhile in the evening. If they did, then one would expect a three versus one interactional CV response pattern. Specifically, effort and associated CV responses should be stronger overall under difficult task conditions in the morning, but relatively low at both difficulty levels in the evening.

CHAPTER 2

METHODS

Participants and Cardiovascular Measurement

Using the SBP findings of Wright et al. (2003), I conducted a power analysis and determined that 125 participants would be needed to achieve 80% power in this study. Following this guide, I recruited 133 University of North Texas undergraduates through the psychology department SONA system. Analyses were run on a total of 122 participants, 11 participants were excluded from analysis due to failures in equipment or data acquisition (n = 10) and one was removed for having extremely high CV values (due to hypertension). It is to also note that three participants came in having drank caffeine before beginning the experiment. CV scores for these participants did not indicate need for removal from the analyses. Participants broke into 81 women and 41 men, with race/ethnicity balanced as: 38 White or Caucasian, 42 Hispanic or Latinx, 25 Black or African American, 11 Asian, and 5 Bi-racial/Multiracial. Demographic data for one participant was not collected.

The participants were first screened for lark chronotype using the Composite Scale for Morningness (Smith, Reilly, & Midkiff, 1989). Using a tertile split those participants who scored above a 37 were considered larks. They were then invited to the lab and randomly assigned to one of four conditions created by the 2 (morning or evening) x 2 (low or high difficulty) factorial design. CV parameters assessed are SBP, DBP, MAP, HR, and PEP. Assessments were made with a BioNex impedance cardiograph amplifier interfaced with a CNAP Technology automatic blood pressure monitor. The amplifier measures electrocardiogram (ECG), thoracic impedance (Z0), and its first derivative (dZ/dt), allowing PEP determinations. The CNAP monitor utilizes an upper arm inflation cuff and a double finger sensor that allows continuous noninvasive measurement of blood pressure and HR. The finger sensor produces a pressure signal that is calibrated by means of a special transfer function to an initial oscillometric value obtained from the arm cuff. It includes balloon-like cuffs placed on the proximal joints of the index and middle fingers. Sampling is continuous during a ten-minute baseline period and, later, a five-minute work period. Participants perform with the chance to earn a modest prize (a UNT pen, keychain, or bottle opener).

Assumptions Regarding Beta-Adrenergic Activation Influence

Beta-adrenergic activation increases the frequency and force of contraction in the left ventricle. HR is sometimes used as a measure of beta-adrenergic activation. However, it is not considered a “pure” measure because it is subject not only to sympathetic nervous system influence, but also to parasympathetic nervous system influence. Whereas sympathetic activation raises HR, parasympathetic activation lowers it. Although the autonomic influences can work in reciprocal fashion, they will not necessarily and can oppose one another. Of special note in relation to the present discussion, parasympathetic activity has potential for reducing, neutralizing, or even reversing effects of increased sympathetic activity.

PEP is considered the most sensitive index of beta-adrenergic activation because it is subject to minimal parasympathetic influence (Kelsey, 2012). As noted previously, PEP is the time interval between the beginning of electrical stimulation to the left ventricle and cardiac ejection of blood from the heart. The higher heart contractility, the shorter the PEP.

SBP is considered an acceptable secondary – downstream – measure of beta-adrenergic activation. SBP is the peak arterial pressure following a heartbeat. It is considered an acceptable secondary measure of beta-adrenergic stimulation because on a given beat it is determined by heart contractility x total peripheral resistance, with the latter reflecting space in the vasculature. As heart contraction force increases, so does the amount of blood that is ejected, typically producing an increase in SBP. An exception would be when a sympathetic discharge produced an offsetting *decrease* in total peripheral resistance, that is, an offsetting increase in vascular space. Whereas a reduction in vascular space should increase SBP, an increase in vascular space could blunt, mask, or even reverse the positive influence of increased heart contraction force on SBP.

Task

The task involved recognition memory, requiring respondents to determine over a series of 40 trials whether a target letter was or was not included in a preceding nonsense series (string) of letters (Sternberg, 1966). On each trial, participants press "yes" or "no" when asked if the letter currently shown was in the string previously presented. For half of the participants, each string consisted of three characters (easy condition); for the rest, each string consisted of seven characters (difficult condition).

Procedure

Participants were met by an experimenter, either male or female. They were asked to leave all personal belongings in a secure hallway and then escorted to the experimental chamber. Once in the chamber, the participants were seated at a desk containing a computer monitor with two consent forms and a brief mood checklist. Incentives were placed near the participants' line of sight. Participants were asked to read the consent form, sign both copies if they were willing to participate, complete the checklist, and then send an intercom CALL signal to the experimenters, who were in the laboratory control room during these activities. The mood checklist asked participants to rate on 11-point scales (0 = not at all, 10 = extremely) the extent to which they felt sleepy, energetic, tired, vigorous, drowsy, lively, wide-awake, quiet, full-of-pep, wakeful, active, fatigued mentally, fatigued physically, nervous, and fearful. Some of these items (e.g., energetic, vigorous) make up the energy subscale of Thayer's (1986) activation-deactivation adjective checklist (ADACL). Other items (e.g., tired, drowsy) make up the tiredness subscale of the ADACL.

Once the experimenters received the CALL signal, the experimenter of the same gender as the participants returned to the experimental chamber and provided a brief overview of the study as being concerned with how people respond psychologically and physiologically when presented different tasks under different conditions. The experimenter elaborated that the physiological responses being analyzed would be HR, PEP and blood pressure, explaining what PEP refers to. After elaboration, the experimenter placed 7 spot electrodes on the participants using MindWare's Electrode Placement Recommended Practices. Electrode placement was followed by placement of the arm and finger cuffs. After this, the experimenter explained that before starting the task there would be a baseline period. During this period, participants were asked to sit quietly for 15 minutes with the option of reading magazines. Magazines were selected for their affectively neutral content. The experimenter returned to the control room, started a stopwatch, and started recording data. CV measures were taken continuously during the baseline period, with the mean of the readings from the 10^{th} – 12^{th} minute being used as the baseline for each CV parameter.

After the baseline period was complete, the experimenter turned a card to randomize condition assignment. The experimenter then re-entered the experimental chamber and handed the participants a folder labeled “Instructions”. The experimenter then provided the participants a computer mouse as to allow them to complete the memory task. Before leaving the experimental chamber, the experimenter told the participants not to open the instructions folder until the experimenter had left the room. The experimenter also reminded the participants that the incentives next to them are the ones described on the informed consent and the instructions. If they attain a certain performance standard, they would be awarded their choice of one of the prizes on display.

The instructions explained to the participants that they would be presented a series of 40 memory trials. Depending on the condition they were assigned to, the participants performed a task that consisted of 3 or 7 letter strings and called for participants to designate whether a single letter was in the preceding string. The string of letters the participants viewed were in Times New Roman with a 72 point font. Participants viewed these strings for 5 seconds and then asked for a response. The task was self-paced, with a response to one trial immediately moving them to the next. Instructions told participants that they should aim to respond correctly at least 85% of the time and that they would be awarded their choice of the prizes on display if they were successful. Instructions also noted that the experimenter would not know the participants’ exact performance score, but would be informed whether they attain their 85% performance target.

Once the participants read the instructions, they pressed the CALL button. This prompted the experimenter to tell them over an intercom system to turn on the computer monitor and begin the task. CV data were recorded continuously during the memorization task. The task took approximately 5 minutes. Once the participants finished all 40 trials, the experimenter stopped recording. At this point, the experimenter directed participants to complete a post-task questionnaire. The post-questionnaire asked participants to rate on 9-point scales (1 = not at all, 9 = very much) the difficulty of the task for them personally, the difficulty of the task for the average person, how personally important it was for them to do well, and how likely it was that they made the 85% performance target. The questionnaire also (1) asked participants whether the experimenter should know whether they attained their 85% performance standard (yes, no), (2) asked participants if the experimenter should award them a choice of prizes if they attained the performance standard (yes, no), and (3) included items from the earlier mood checklist. A final demographics questionnaire asked participants their age, sex, gender identity, and ethnicity.

Once the participants completed their questionnaire, they pressed the intercom CALL button and the experimenter returned to the chamber for debriefing. Debriefing was followed by the awarding of SONA credits and the prize. A prize was awarded regardless of performance. Sessions lasted no more than 45 minutes.

Statistical Analyses

Baseline CV values were analyzed to determine if groups differed prior to interventions. Data were examined with analyses of variance (ANOVAs) involving the main design factors. CV responsiveness was measured as CV change (Δ) from baseline, computed by subtracting base values from work values (Llabre, Spitzer, Saab, Ironson, & Schneiderman, 1991). Central predictions for PEP and SBP were examined with planned contrasts and pair-wise comparisons using t-tests. The planned contrasts constituted the interaction contrast from a conventional ANOVA, with coefficients of: -1 (easy/morning), +1 (difficult/morning), +1 (easy/evening), and -1 (difficult/evening). Change scores for DBP, MAP, and HR were examined with conventional ANOVA (main effect and interaction) contrasts with follow-up pair-wise comparisons where appropriate.

Performance data were analyzed with ANOVAs and simple effect tests. Mood checklist Δ-scores were computed by subtracting base affect ratings from work period ratings and analyzed with ANOVAs. Baseline mood values were examined with ANOVAs and simple effects tests. Energy and Tiredness ADACL subscales were compiled prior to mood score analyses. Subscales were highly correlated at baseline ($r = -.61$, $p < .001$) and in terms of change ($r = -.57$, $p < .001$). Further, they have been combined previously to create an index of fatigue (Mlynski, Wright, Agtarap, & Rojas, 2017; Nolte et al., 2008), with higher values indicating higher fatigue (lower energy, higher tiredness). Consequently, I combined the subscales here to create a fatigue index possibly indicative of larks' different subjective experience working in the morning and evening. Preliminary analysis indicated that responses to the first two post-task questionnaire items – pertaining to difficulty – were highly correlated ($r = .73$, $p < .001$), with mean ratings distributed similarly across conditions. Consequently, I combined those into a single difficulty index. The difficulty index and responses to the other post-task questionnaire items were examined with ANOVAs. Responses to the two yes, no questions pertaining to the experimenter's knowledge of their performance and the awarding of the prizes were examined with logistic regression.

My original analytic plan was to perform analyses initially including gender as a factor, collapsing across that factor if there were no effects. Preliminary analysis in fact revealed concerning gender effects on the key difficulty index above. Men had higher difficulty ratings overall, $F(1, 114) = 4.65$, $p = .03$, $\eta_p^2 = .04$; further, there was a triple interaction, $F(1, 114) = 5.85$, $p = .017$, $\eta_p^2 = .05$, with the interaction indicating that the difficulty manipulation was effective for women in both the morning and evening sessions, but effective for men only in the evening session. Predictions for CV response were predicated on assumptions pertaining to difficulty appraisals. Consequently, I decided to examine findings for women and men separately.

Two considerations indicated that CV findings would be less informative for men. One was the suggestion that the difficulty manipulation was ineffective for men in the morning session. The other was the smaller number of male participants, particularly in the easy/morning condition. Whereas *n*s for women were respectable in the easy/morning (26), difficult/morning (21), easy/evening (18), and difficult/evening (16) conditions, those for men fell short of what normally would be accepted (easy/morning, 6; difficult/morning, 12; easy/evening, 11; difficult/evening, 12).

CHAPTER 3

RESULTS

Data for Women

Cardiovascular Measures

Baseline

Baseline means, standard deviations, and *n*s are in Table 2. Analysis revealed no effects, indicating no group differences at rest, *Fs* < .86, *ps* > .40.

Table 2

Baseline Pre-Ejection Period, Blood Pressure, and Heart Rate for Women

Difficulty	Morning		Evening	
	Easy	Difficult	Easy	Difficult
PEP	94.78 (21.73)	93.30 (18.89)	85.43 (21.42)	89.52 (19.67)
n	25	20	14	15
SBP	110.59 (12.03)	107.86 (10.52)	108.78 (10.26)	109.16 (109.53)
n	26	19	14	14
DBP	73.89 (7.97)	73.15 (6.06)	74.39 (6.93)	75.08 (8.46)
n	26	19	14	14
MAP	86.48 (8.49)	84.72 (7.02)	85.84 (7.12)	86.56 (9.05)
n	26	19	14	14
HR	76.71 (13.86)	79.29 (14.12)	84.62 (16.22)	80.74 (15.46)
n	25	20	14	15

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial pressure; HR = heart rate; *n* = cell *n*. Blood pressure is quantified in millimeters of mercury (mmHg). HR is quantified in beats per minute (bpm). Lower PEP values indicate *stronger* heart contractility. For each measure, means are followed by standard deviations in parentheses.

Cardiovascular Change

Means, standard deviations, and *n*s are in Table 3. Analyses indicated (1) a difficulty x time interaction for MAP, F (1, 64) = 5.88, p = .018, η_p^2 = .08, and (2) difficulty effects for DBP, F (1, 64) = 4.60, p = .036, η_p^2 = .07, and HR, F (1, 70) = 4.74, p = .033, η_p^2 = .06. The interaction for MAP reflected a crossover response pattern consistent with that originally expected for effort (Figure 2, upper left panel). Follow-up pair-wise comparisons indicated that responses were stronger for the difficult task (as compared to the easy task) in the morning, t (64) = 3.31, p = .002, and stronger in the evening (as compared to the morning) for the easy task, t (64) = 1.98, p = .052. The main effects for DBP and HR reflected stronger responses under difficult conditions (Figure 2, lower left and right panels). Although interactions were not reliable for DBP and HR, it is of note that main effects for both measures were carried by responses in the morning. Pair-wise comparisons indicated that responses were stronger for the difficult task (as compared to the easy task) in the morning [DBP: t (64) = 3.15, p = .025; HR: t (64) = 1.98, p = .052], but not in the evening.

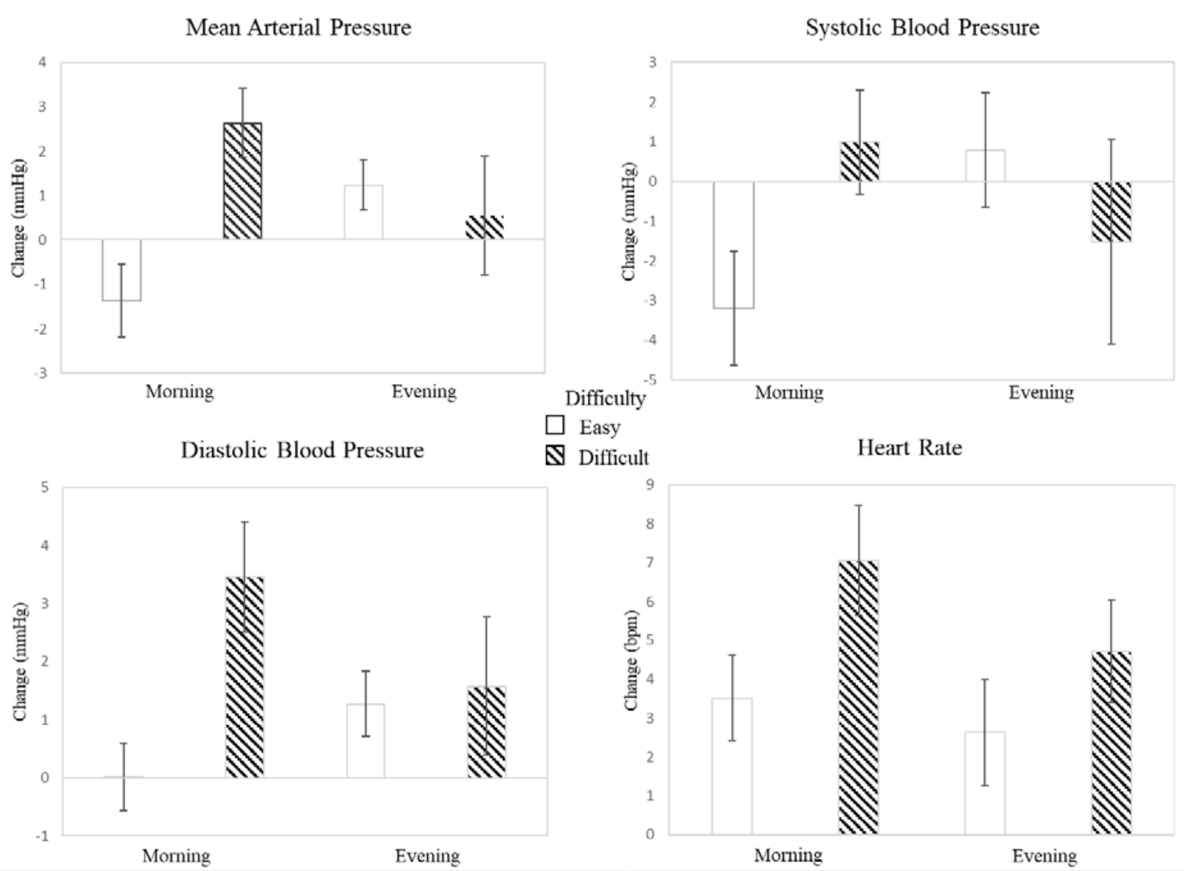

Figure 2. Cardiovascular change in blood pressure and HR. Blood pressure is quantified in millimeters of mercury (mmHg). HR is quantified in beats per minute (bpm). Error bars indicate standard errors.

Inspection of SBP responses in Table 3 and Figure 2 shows that they ran in parallel to those for MAP, with the difficulty x time interaction for that measure approaching significance (p =. 078). Planned pair-wise comparisons indicated that SBP responses tended to be stronger for the difficult task (as compared to the easy task) in the morning, t (64) = 1.86, p = .068, and tended to be stronger in the evening (as compared to the morning) for the easy task, t (64) = 1.64, p = .106. ANOVA effects for PEP fell well short of significance (ps ≥ .174), although the PEP response pattern corresponded with other CV response patterns in some respects (Table 3). Planned pair-wise comparisons indicated that PEP responses tended to be stronger for the difficult task (as compared to the easy task) in the morning, t (70) = 1.68, p = .097, and tended to be stronger in the morning (as compared to the evening) for the difficult task, t (70) = 1.85, p = .069. Recall that lower PEP change scores indicate *greater* increases in heart contraction force.

Table 3

Cardiovascular Change Score Pre-ejection Period, Blood Pressure, and Heart Rate for Women

Difficulty	Morning		Evening	
	Easy	Difficult	Easy	Difficult
PEP	-2.88 (4.76)	-5.30 (4.65)	-3.00 (4.42)	-2.26 (5.39)
n	25	20	14	15
SBP	-3.20 (7.28)	.99 (5.74)	.79 (5.43)	-1.52 (9.66)
n	26	19	14	14
DBP	.02 (2.93)	3.46 (4.14)	1.27 (2.11)	1.58 (4.46)
n	26	19	14	14
MAP	-1.37 (4.14)	2.64 (3.39)	1.24 (2.12)	.54 (5.02)
n	25	19	14	14
HR	3.52 (5.51)	7.06 (6.32)	2.63 (5.11)	4.72 (5.10)
n	25	20	14	15

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial pressure; HR = heart rate; n = cell n. Blood pressure is quantified in millimeters of mercury (mmHg). HR is quantified in beats per minute (bpm). Lower PEP change values indicate *stronger* heart contractility. For each measure, means are followed by standard deviations in parentheses.

Subjective Measures

Baseline Affect

Baseline means, standard deviations, and *n*s are in Table 4. Analysis revealed no effects, indicating no group differences at rest, *Fs* < 1.85 *ps* > .15.

Table 4

Baseline Affect Responses for Women

Difficulty	Morning		Evening	
	Easy	Difficult	Easy	Difficult
Fatigue Index	4.62 (.78)	4.89 (.69)	4.58 (.59)	4.42 (.93)
Mentally Sharp	6.50 (1.58)	7.43 (1.50)	6.67 (1.85)	6.81 (1.42)
Foggy Headed	1.77 (2.08)	2.19 (2.29)	2.50 (2.46)	2.00 (2.00)
Clear Minded	6.85 (1.74)	7.48 (1.50)	6.94 (2.39)	6.81 (2.04)
Mentally Dull	2.04 (1.87)	2.24 (2.41)	2.28 (2.52)	2.31 (2.22)
Fatigued Mentally	2.23 (2.14)	3.33 (2.63)	3.50 (2.99)	2.88 (2.39)
Fatigued Physically	2.54 (2.80)	3.48 (2.98)	3.33 (2.72)	2.81 (2.19)
Nervous	2.65 (2.46)	2.10 (2.51)	2.11 (2.56)	1.56 (2.50)
Fearful	1.19 (1.89)	.81 (1.63)	1.44 (2.06)	.63 (1.63)
Quick Witted	5.00 (2.02)	5.43 (2.66)	5.17 (2.50)	5.63 (2.85)
n	26	21	18	16

Note. *n* = number of participants in each condition. For each measure, means are followed by standard deviations in parentheses.

Post-Task Questionnaire Including Affect Change Scores

Means, standard deviations, and *n*s for the difficult index, the importance question, and the likelihood of success question are in the upper portion of Table 5. Analyses indicated difficulty effects for the index, F (1, 77) = 44.76, $p < .001$, $\eta_p^2 = .37$, and the likelihood measure, F (1, 77) = 21.60, $p < .001$, $\eta_p^2 = .22$. Difficulty ratings were higher and likelihood ratings were lower in the difficult conditions. It can be seen in the table that importance scores were relatively high for all participants, although they did not closely approach the scale upper bound of 10.

Table 5

Post-Task Questionnaire Responses and Affect Change-Scores for Women

Difficulty	Morning		Evening	
	Easy	Difficult	Easy	Difficult
Difficulty Index	.98 (.74)	3.38 (1.80)	1.08 (.94)	2.88 (1.91)
Personal Importance	7.08 (2.62)	6.81 (2.34)	7.33 (2.66)	7.81 (1.97)
Success Likelihood	9.23 (2.10)	6.71 (2.05)	8.94 (1.35)	7.38 (2.09)
Experimenter Should Know	76%	90%	94%	94%
Experimenter Should Award	85%	95%	89%	94%
Fatigue Index	-.62 (.68)	-.78 (.48)	-.33 (.68)	-.68 (.44)
Mentally Sharp	1.00 (1.74)	.19 (1.12)	.72 (1.27)	.63 (1.26)
Foggy Headed	5.08 (2.98)	4.95 (3.47)	4.17 (4.05)	4.56 (3.46)
Clear Minded	-.08 (1.29)	.24 (1.51)	-.28 (1.64)	.50 (2.16)
Mentally Dull	3.35 (2.51)	3.33 (3.45)	3.17 (4.09)	3.25 (3.68)
Fatigued Mentally	-.42 (1.17)	-.76 (1.92)	.22 (1.52)	-1.13 (1.75)
Fatigued Physically	-.04 (1.46)	-.67 (2.01)	.06 (1.35)	-.75 (1.06)
Nervous	-1.77 (2.16)	-.14 (1.53)	-.50 (1.82)	-.75 (2.54)
Fearful	-.65 (1.62)	.14 (.73)	-.61 (1.33)	-.25 (1.91)
Quick Witted	-.54 (2.14)	-.81 (2.91)	-.66 (2.49)	-1.13 (2.65)
n	26	21	18	16

Note. *n* = number of participants in each condition. For each rated measure, means are followed by standard deviations in parentheses. Percent values represent percent of yes responses.

Table 5 also presents by condition the percent of participants who confirmed that the experimenter should (1) know whether they attained the 85% performance standard, and (2) award them a prize if they did. Analysis revealed no group differences, with strong “yes” confirmation in all conditions.

Means, standard deviations, and *n*s for the affect change scores are in the lower portion of Table 5. Analyses indicated only a difficulty x time interaction for the item "nervous", F (1, 77) = 4.19, p = .044, η_p^2 = .05. Nervousness decreased between baseline and the post-task period in the morning, t = -1.62, p = .005, but was relatively low in both difficulty conditions in the evening.

Performance

Analysis indicated a difficulty effect, F (1, 77) = 53.33, p < .001, η_p^2 = .41, and a difficulty x time interaction, F (1, 77) = 4.69, p = .033, η_p^2 = .06. As seen in Figure 3, performance was poorer in the difficult conditions and the decline in performance between easy and difficult was greater in the morning, t (77) = 7.29, p <.001, than in the evening, t (77) = 3.37, p = .001. Whereas performance on the easy task did not differ as a function of time, performance on the difficult task was poorer in the morning, t (77) = 2.60, p = .012.

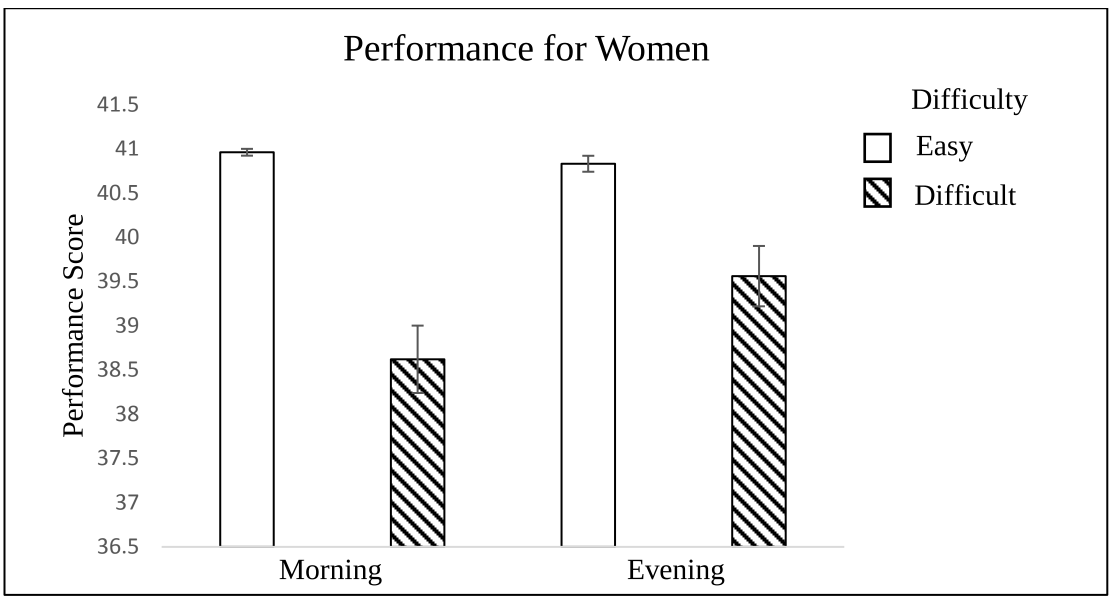

Figure 3. Mean performance scores with standard errors.

Data for Men

Cardiovascular Measures

Baseline

Baseline means, standard deviations, and *n*s are in Table 6. Analysis revealed no effects, indicating no group differences at rest, $Fs < 1.77$, $ps > .20$.

Table 6

Baseline Pre-ejection Period, Blood Pressure, and Heart Rate for Men

Difficulty	Morning		Evening	
	Easy	Difficult	Easy	Difficult
PEP	102.33 (31.66)	105.64 (18.06)	90.44 (21.72)	86.73 (18.40)
n	6	11	9	11
SBP	114.46 (9.70)	114.78 (10.46)	119.44 (19.14)	119.03 (5.51)
n	5	12	9	10
DBP	73.04 (7.35)	76.37 (8.18)	76.80 (13.94)	77.56 (4.82)
n	5	12	9	10
MAP	86.84 (7.59)	89.17 (7.57)	91.01 (15.01)	91.33 (3.14)
n	5	12	9	10
HR	71.32 (8.40)	72.51 (13.81)	79.67 (16.40)	80.96 (5.89)
n	5	12	11	12

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial pressure; HR = heart rate; *n* = cell *n*. Blood pressure is quantified in millimeters of mercury (mmHg). HR is quantified in beats per minute (bpm). Lower PEP values indicate *stronger* heart contractility. For each measure, means are followed by standard deviations in parentheses.

Cardiovascular Change

Means, standard deviations, and *n*s are in Table 7. Analyses indicated no differences among groups on any of the CV measures, $Fs < 2.00$, $ps > .16$.

Table 7

Pre-Ejection Period, Blood Pressure, and Heart Rate Change for Men

Difficulty	Morning		Evening	
	Easy	Difficult	Easy	Difficult
PEP	-5.67 (6.38)	-6.18 (5.33)	-5.33 (8.00)	-3.27 (3.38)
n	6	11	9	11
SBP	-1.70 (4.50)	-2.57 (6.07)	.18 (5.00)	3.35 (7.00)
n	5	12	9	10
DBP	-.50 (4.95)	-.18 (3.23)	2.59 (5.09)	5.92 (7.61)
n	5	12	9	10
MAP	-.89 (3.96)	-.81 (2.29)	1.88 (4.48)	3.12 (4.48)
n	5	12	9	10
HR	2.63 (3.22)	2.99 (4.28)	3.42 (4.11)	5.24 (7.00)
n	5	12	11	12

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial pressure; HR = heart rate; *n* = cell *n*. Blood pressure is quantified in millimeters of mercury (mmHg). Lower PEP change values indicate *stronger* heart contractility. HR is quantified in beats per minute (bpm). For each measure, means are followed by standard deviations in parentheses.

Subjective Measures

Baseline Affect

Baseline means, standard deviations, and *n*s are in Table 8. Analysis revealed no effects, indicating no group differences at rest for subjective affect items, *Fs* < 1.85, *.ps* > .15.

Table 8

Baseline Affect Scores for Men

Difficulty	Morning		Evening	
	Easy	Difficult	Easy	Difficult
Fatigue Index	4.65 (.92)	4.87 (.91)	5.00 (.74)	4.63 (1.06)
Mentally Sharp	7.50 (1.05)	7.00 (1.86)	7.73 (.79)	7.23 (.79)
Foggy Headed	3.00 (2.53)	2.45 (2.73)	2.64 (2.87)	2.83 (2.33)
Clear Minded	7.83 (1.17)	6.75 (2.09)	7.10 (1.97)	6.58 (1.56)
Mentally Dull	2.67 (2.07)	2.83 (2.33)	2.36 (2.73)	2.71 (2.05)
Fatigued Mentally	2.66 (2.06)	2.42 (2.68)	3.18 (2.44)	3.67 (1.97)
Fatigued Physically	3.67 (3.33)	2.83 (2.89)	4.27 (3.38)	3.33 (2.27)
Nervous	1.33 (.82)	2.58 (2.81)	2.09 (2.26)	3.00 (3.30)
Fearful	.17 (.41)	.58 (1.16)	.91 (1.30)	1.92 (2.57)
Quick Witted	4.17 (3.49)	6.00 (2.37)	6.00 (1.79)	4.83 (2.41)
n	6	12	11	12

Note. *n* = number of participants in each condition. For each measure, means are followed by standard deviations in parentheses

Post-Task Questionnaire Including Affect Change Scores

Means, standard deviations, and *n*s for the difficult index, the importance question, and the likelihood of success question are in the upper portion of Table 9. Analysis of the difficulty index revealed a difficulty effect, F (1, 37) = 7.83, p = .008, η_p^2 = .18, qualified by a marginally significant difficulty x time interaction, F (1, 37) = 3.87, p = .057, η_p^2 = .10. Pair-wise comparisons indicated that values were higher under difficult- than easy conditions in the evening, t (37) = 3.72, p = .001, but not in the morning, t (37) = .92, p = .591. Analysis of the likelihood measure indicated effects for difficulty, F (1, 37) = 8.13, p = .007, η_p^2 = .18, and time, F (1, 37) = 5.18, p = .029, η_p^2 = .12. Likelihood ratings were lower in the difficult conditions and in the morning. Importance scores were relatively high in all conditions although they did not closely approach the scale upper bound of 10.

Table 9

Post-Task Questionnaire Responses and Affect Change-Scores for Men

Difficulty	Morning		Evening	
	Easy	Difficult	Easy	Difficult
Difficulty Index	2.67 (2.73)	3.17 (1.44)	1.14 (1.12)	4.00 (2.21)
Personal Importance	8.33 (1.03)	6.33 (2.99)	7.45 (2.46)	8.50 (2.35)
Success Likelihood	8.50 (1.52)	6.75 (2.53)	9.73 (.47)	8.17 (1.75)
Experimenter Should Know	100%	83%	83%	92%
Experimenter Should Award	100%	83%	100%	83%
Fatigue Index	-.88 (.85)	-.80 (.69)	-.74 (.70)	-.80 (.65)
Mentally Sharp	-1.00 (2.00)	-.09 (1.56)	-1.00 (1.10)	-.58 (1.24)
Foggy Headed	4.67 (3.20)	4.72 (3.29)	4.82 (3.74)	4.08 (2.97)
Clear Minded	-.67 (1.37)	.67 (1.87)	.27 (2.23)	1.17 (2.44)
Mentally Dull	1.83 (3.19)	3.08 (3.92)	3.82 (3.71)	3.21 (3.19)
Fatigued Mentally	-1.00 (2.00)	-.08 (1.56)	-1.00 (1.10)	-.58 (1.24)
Fatigued Physically	-.50 (1.37)	-.67 (1.37)	-2.18 (2.71)	-.58 (1.24)
Nervous	-.50 (1.22)	-.75 (2.10)	-1.64 (2.20)	-.83 (1.27)
Fearful	.50 (.55)	-.25 (.75)	-.73 (1.19)	-.17 (1.59)
Quick Witted	-.17 (1.17)	-1.08 (1.88)	-.64 (1.69)	.58 (1.68)
n	6	12	11	12

Note. *n* = number of participants in each condition. For each measure, means are followed by standard deviations in parentheses.

Table 9 also presents by condition the percent of participants who confirmed that the experimenter should (1) know whether they attained the 85% performance standard, and (2) award them a prize if they did. Analysis revealed no group differences, with strong “yes” confirmation in all conditions.

Means, standard deviations, and *n*s for the affect change scores are in the lower portion of Table 9. Analysis revealed no effects, indicating no group differences in change scores for affect items, $Fs < 1.39$, $ps > .25$.

Performance

Analysis indicated a main effect for difficulty, F (1, 37) = 18.39, p <.001, η_p^2 = .33. As seen in Figure 4, the difficulty effect reflected poorer performance in the difficult conditions [morning M = 38.42 (SD = 1.92); evening M = 39.50 (SD = 1.68)], than in the easy conditions, [morning M = 40.83 (SD = .41); evening M = 41.00 (SD = .41)].

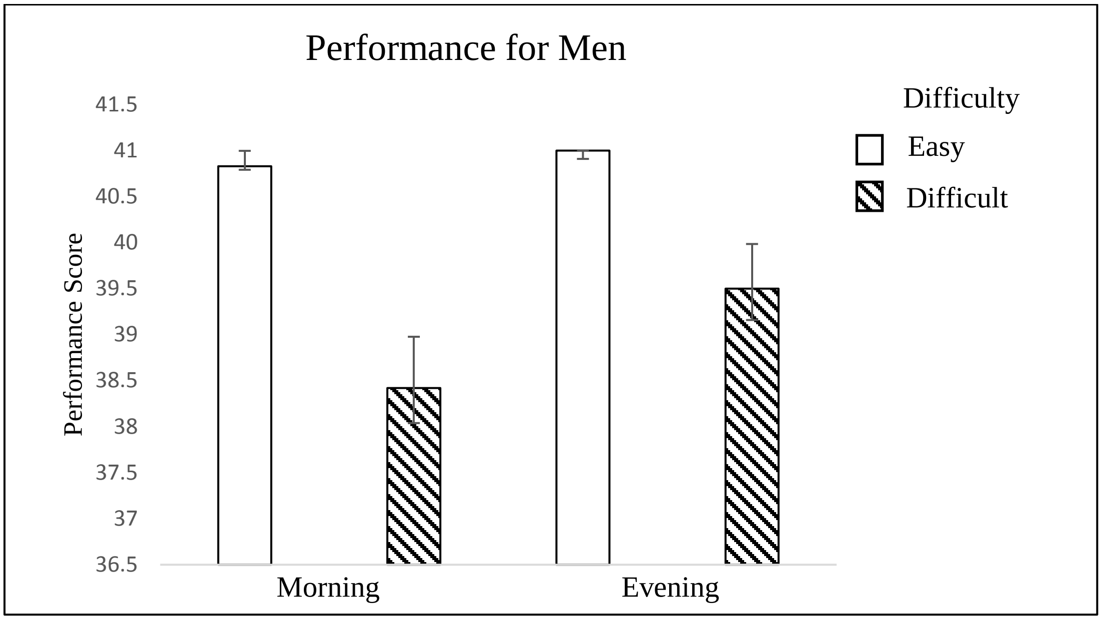

Figure 4. Mean performance scores with standard errors.

CHAPTER 4

DISCUSSION

This study examined CV responses of student larks assigned an easy or difficult recognition memory challenge in the morning or in the evening. Based on the fatigue analysis described in this paper, the prediction was that effort and associated CV responses would form an interactional pattern - rising with difficulty in the morning, but falling with difficulty in the evening. However, I recognized that different effort and CV response patterns could emerge and still be consistent with the fatigue analysis. For example, one could expect two main effects for effort and associated CV responses, with the responses being stronger under difficult conditions, and in the evening. Alternatively, one could expect a three versus one interactional response pattern, reflecting stronger effort and CV responsiveness under difficult conditions in the morning, but low effort and CV responsiveness irrespective of difficulty in the evening.

Gender effects were not predicted, but gender was included in preliminary analyses to confirm that none were present. Preliminary analysis revealed gender effects on a key difficulty measure. Men had higher difficulty ratings overall; moreover, the ratings indicated that the difficulty manipulation was effective for women in both the morning and evening sessions, but effective for men only in the evening session. The crossover prediction was based on assumptions pertaining to difficulty appraisals. Because of this, findings for women and men were analyzed separately, with the understanding that findings for men would be less interpretable than those for women.

Findings for Women

My results showed that lark women in the morning had stronger MAP, DBP, and HR responses under the difficult task conditions, as well as a tendency for stronger SBP and PEP responses. I also found that responses for MAP and SBP on the easy task tended to be stronger in the evening, and PEP responses to the difficult task were stronger in the morning. However, whereas some evening CV responses, like those for MAP, showed a decreasing trend from the easy task to the difficult task, there were no evening difficulty effects that approached statistical significance. An explanation for this response pattern could be that the expected effort effects were present, but weaker in the evening than in the morning.

Analysis of the difficulty index ratings indicated that the manipulation of difficulty was successful. Ratings were higher for the difficult task than for the easy task. This was supported by the likelihood of success ratings, which were lower among those assigned the difficult task. However, time effects were not found for the difficulty index ratings or the likelihood of success ratings. Related to these findings are findings on the baseline affect data, which provided no evidence of greater fatigue or reduced cognitive clarity in the evening. The absence of time effects on the preceding measures does not bear out the fatigue analysis extension to circadian mismatch. On the other hand, it is consistent with subjective findings in the circadian studies mentioned earlier, which showed inconsistent relations between circadian match and measures of arousal, negative affect, and other subjective measures. It also might be interpreted in terms of the possibility that mismatch might sometimes have subtle, even fully implicit (nonconscious), effects on difficulty, fatigue, and clarity (Richter, Gendolla, & Wright, 2016). These effects could impact CV responses, but not be detected easily or detected at all. Support for this possibility comes from recent experiments that implicitly altered appraisals of difficulty through visual (e.g., facial and word) primes (e.g., Gendolla, 2015). The primes were found to produce expected CV responses without affecting subjective reports of difficulty.

Related to the preceding suggestion, another possible explanation for the lack of time effects on the measures above is that the measures were relatively insensitive – not capable of detecting what might have been modest differences in difficulty, fatigue, and clarity. I see support for this suggestion in the affect change score results. I would expect that the morning participants in the difficult condition would have shown increased fatigue and decreased cognitive clarity from baseline to post-task relative to morning participants in the easy condition. However, analyses showed no such effect, possibly because my measures were not sufficiently sensitive to detect it.

Results on the performance measure showed that those in the difficult condition had poorer performance and the decline between easy and difficult was steeper in the morning than it was in the evening. Following the guiding fatigue analysis, one might expect the reverse to have occurred: a steeper easy-to-difficult decline in performance in the evening condition. However, this expectation would assume a direct relation between effort and performance on the task, which might not have been present. It has been shown that improved effort does not necessarily mean improved performance. On some tasks, counterproductive effects have been demonstrated, with improved effort leading to no performance improvement or even a decline in performance. In a real world scenario, this could be thought of as trying one's best on the SAT but not getting a score higher than was attained in practice exams. An important consideration is the degree to which a task involves response conflict (Harkins, 2006). It could be that the interaction pattern in my study reflects a counterproductive effort effect in those participants assigned to the morning difficult condition.

Results on the questions pertaining to the experimenter's awareness of the participants' performance and duty to award an incentive if the performance standard was attained were as expected. The vast majority of participants confirmed the appropriate understanding and the percent of confirmations did not vary by difficulty or time.

Findings for Men

No group differences were found for CV responses in men. These results are difficult to interpret because of a small sample and uneven cell sizes. However, it is worth considering whether the null CV response effects were related to men's appraisal of difficulty. Analysis of the difficulty index found the manipulation for difficulty was only successful for the evening group; with a visible interactional response pattern where values were higher for the difficult task only in the evening. If morning men in both conditions had rated the task as equally difficult, we would expect them to show similar effort and CV responses, which was not entirely the case. Explanations into why this occurred could be made in regard to problems with the manipulation, where a weak manipulation might produce some effects, but a strong manipulation producing all predicted effects. Another explanation is the possibility that men in the morning conditions did not see success as important or worthwhile, making them more inclined to withhold effort. However, the means for success importance do not support this, but this could be because of our small sample. There is also the possibility that some participants showed a bias to report high importance regardless of whether success was actually important to them.

Results on the performance data showed that performance was poorer in the difficult conditions. No interaction was present and this could be due to low power. The performance means followed a similar pattern as those for women. Similarly, results on the questions pertaining to the experimenter's awareness of the participants' performance and duty to award an incentive if the performance standard was attained were as expected. Most participants confirmed the appropriate understanding and the percent of confirmations did not vary by difficulty or time.

Implications, and Directions for Future Research

In summary, CV findings for women were broadly, but not completely, consistent with predictions, with inconsistencies possibly relating to perceptions of whether effort was worthwhile or not for some evening participants. CV findings for men were not consistent with our predictions, with the men's responses not being affected by difficulty or time. Interpretation for men's findings is difficult, considering that *n*s were low and uneven, thus leading to low power and limited ability to detect effects. However, the findings could reflect the influence of a weak or ineffective difficulty manipulation in the morning or unexpectedly low success importance appraisals among the morning participants.

Given the number of uncertainties associated with these results, it is important not to draw too much from them. On the other hand, the results for women are encouraging and support the continued pursuit of the fatigue analysis extension to the circadian mismatch phenomenon. Insofar as the extension is borne out in future studies, it will have a range of implications, including ones for health. Regarding health, prevailing health models assume that chronically elevated CV responses confer risk for various adverse outcomes such as heart disease, stroke, and dementia (de la Torre, 2010; de la Torre & Mussivand, 1993; Krantz & Manuck, 1984; Smith & Ruiz, 2002). To the degree this is the case, there is the suggestion that circadian mismatch could sometimes increase health risk. Specifically, one would expect it to do so under conditions where mismatched performers are consistently presented challenges that they are strongly pressed to meet. Consider for example a single parent owl pressed to meet heavy workplace challenges each morning so he can be free to address child care responsibilities in the evening. The parent would likely meet the challenges because doing so would be necessary to support his family. Because he was an owl chronotype, he would be expected to exert especially high effort and evince especially strong – and potentially toxic - CV responses in the process.

An immediate need is for a follow-up study that presents people of the owl chronotype the same easy and difficult tasks used here. This will serve as a conceptual replication of the present study with key theoretical predictions following in reverse. That is, owls should evince effort and associated CV response patterns that directionally oppose the response patterns predicted here for larks. Additional studies should extend the range of difficulty levels, evaluate explicitly the role of success importance, and contrast responses of larks and owls in context of single research designs. They also could (1) examine the influence of (e.g., caffeine) interventions designed to reduce or eliminate fatigue in mismatched performers, and (2) examine CV responses in larks and owls outside of the laboratory, for example, through ambulatory monitoring at work. Insofar as fatigue interventions are effective, they should alter in predictable fashions CV response patterns ordinarily observed. And insofar as findings in the laboratory have external validity, they should be detectable in real world contexts.

Still further directions for future research could include ones oriented toward better understanding gender differences and, separately, the phenomenon of behavioral restraint, that is, active resistance against an urge or impulse to act in some fashion. A recent analysis of restraint by Wright and Agtarap (2015) suggests that restraint effort can be understood in the same terms that effort toward any other purpose can be understood. If this is true, it implies that fatigue associated with circadian mismatch should impact predictably restraint effort, with CV and possibly restraint performance outcomes following. Implications for behavioral control are manifold and would well be worth investigation both in the laboratory and in real world settings.

Limitation and Conclusion

A notable limitation of this research pertains to the sample of larks in the evening sessions. Even for women, ns were smaller than desired. I discovered in the course of running this study that UNT undergraduates are overwhelmingly owls. This makes evening recruitment of larks difficult.

By way of conclusion, this experiment generated promising support for the fatigue analysis extension to the phenomenon of circadian mismatch among women, but not among men. Insofar as the extension is borne out in future studies, it will have a range of implications, including ones for health. Future studies can expand in numerous ways upon the present research, including owls as well as larks, testing theoretical assumptions, and evaluating fresh applications, for example, to special challenges such as ones involving behavioral restraint.

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